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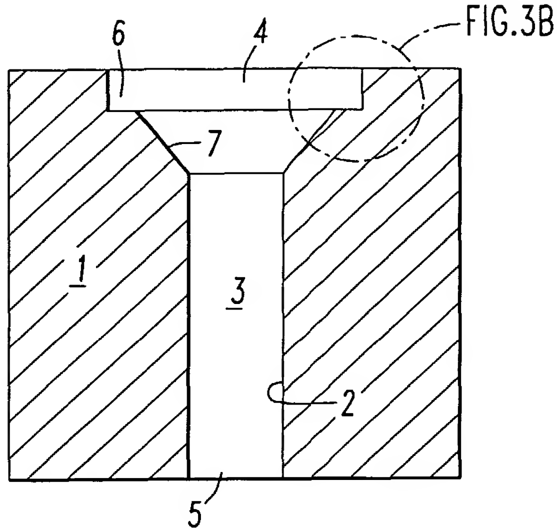
(54) Title: IMPROVED REGULATION OF A STREAM OF MOLTEN METAL



(57) Abstract: The invention describes an article for reducing precipitation on a surface adjacent to a stream of molten steel that is flowing from one metallurgical vessel to a second metallurgical vessel or mold. The refractory article comprises a working surface having a perturbation that disrupts the laminar flow in a boundary layer adjacent to the surface. The resultant non-laminar flow reduces precipitation on the surface and provides a convenient point for the injection of inert gas. The method includes disrupting the laminar flow in a boundary layer adjacent to the working surface.

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IMPROVED REGULATION OF A STREAM OF MOLTEN METAL

Field of the Invention

The present invention relates to refractory articles and methods for use in the casting of molten metal, and particularly to such articles and methods affecting the flow of a molten metal between metallurgical vessels or molds.

Description of the Related Art

In the continuous casting of steel, refractory articles permit the transfer of molten steel between various containers, notably between the ladle and the tundish, and the tundish and the continuous casting mold. Such articles include stopper rods, inner nozzles, metering nozzles, slide gate plates and pour tubes, such as shrouds and nozzles, which have at least one surface contacting the stream of molten steel. The surface can be an outer surface, such as a nose of a stopper rod, or an inner surface, such as a bore through which the molten steel flows.

An important function of refractory articles that contact the flow of molten steel is to discharge the molten steel in a smooth and steady manner without interruption or disruption. A smooth, steady discharge facilitates processing, reduces costs, and can improve the finished product.

Factors, which can disrupt the steady discharge, include asymmetric flow of molten steel and clogging of the bore. Asymmetric flow may develop at the entrance of or within the bore. During casting, precipitates can accumulate near the entrance of a bore and can affect the stream's velocity across the bore. For example, the stream may develop higher fluid velocity near the centerline of the bore than along the sides of the bore, or lower velocity on one side of the centerline as compared to the

opposite side, or higher fluid velocity off the centerline. The disparate velocities can cause pulsing and excessive turbulence upon exiting the bore, thereby complicating processing and decreasing the quality of the finished product.

Precipitates may also clog or restrict the bore so as to disrupt steady discharge of the molten metal. In molten steel, precipitates include high melting point impurities, such as alumina and titania. An oxygen lance can be used to dislodge the precipitate and unclog the bore; however, lancing disrupts the casting process, reduces refractory life, and decreases casting efficiency and the quality of the steel produced. A total blockage of the bore by precipitates decreases the expected life of the pour tube and is very costly and time-consuming to steel producers.

Prior art attempts to improve flow include both chemical and mechanical means. For example, flow may be improved by reducing precipitates and subsequent clogging. Prior art has injected inert gas into the pour tube to shield the flow from the pour tube, thereby reducing precipitation and clogging. Unfortunately, gas injection requires large volumes of gas, complicated refractory designs, and is not always an effective solution. Gas may also dissolve or become entrapped within the metal causing problems in metal quality including pinhole defects in the steel. Alternatively or in combination with gas injection, prior art has lined the bore with refractory compositions that are claimed to resist precipitation. Compositions include lower melting point refractories, such as CaO-MgO-Al_2O_3 eutectics, MgO, calcium zirconate and calcium silicide, that slough off as deposits form on surfaces. These compositions tend to crack at high temperature, and, during casting, they may hydrate and dissipate. For these reasons, their useful life is limited. Other surface compositions that claim to inhibit deposition include refractories containing SiAlON-

graphite, metal diborides, boron nitrides, aluminum nitride, and carbon-free compositions. Such refractories can be expensive, impractical, and manufacturing can be both hazardous and time consuming.

Mechanical designs for improving flow include U.S. Pat. No. 5,785,880 to Heaslip et al., which teaches a pour tube having a diffusing geometry that smoothly delivers a stream of molten metal to a mold. Alternative designs include EP 0 765 702, which describes a perforated obstacle inside the bore that deflects the stream from a preferred trajectory. Both references attempt to control the introduction of molten metal into a mold by mechanically manipulating the stream of molten metal. Neither attempts to reduce precipitation or clogging.

Prior art also includes designs that claim to improve flow by reducing precipitation within the bore. These designs include pour tubes with both conical and "stepped" bores. U.S. Pat. No. 4,566,614 to Frykendahl teaches an inert gas-injection nozzle having a conical bore intended to reduce "pulsations" in the gas flow. Smoother gas flow into the bore is said to reduce clogging. "Stepped" designs include pour tubes that have discontinuous changes in bore diameter. Stepped designs also include pour tubes having a spiral bore. JP Kokai 61-72361 is illustrative of stepped pour tubes, and describes a pour tube having a bore with at least one convex or concave section that generates turbulent flow in the molten metal. Turbulent flow, as contrasted with laminar flow, is described as reducing alumina clogging. U.S. Pat. No. 5,328,064 to Nanbo et al. teaches a bore having a plurality of concave sections separated by steps having a constant diameter, d. Each section has a diameter greater than d, and preferably the diameters of the sections decrease along the direction of flow. The steps are described as generating turbulence that reduces alumina clogging.

PCT/US00/23601 to Heaslip et al. comprises a pour tube having a bore comprising a series of fluidly connected sections each of which converges and diverges to continuously alter and diffuse the contained stream.

Prior art designs are directed at reducing precipitation and clogging by altering the bulk flow of molten steel within a bore. A need persists for a refractory article that inhibits precipitation and clogging at the inlet and outlet of a bore while maintaining flow patterns consistent with a smooth and steady discharge of molten steel from the article. Such an article should also reduce turbulence in a mold and extend the life of the refractory article. Ideally, the article could be adapted for use in combination with inert gas.

Summary of the Invention

The objective of the present invention is a refractory article and a method of making the article that is used in the transfer of molten steel from a first metallurgical vessel to a second metallurgical vessel or mold. The article includes a surface contacting a stream of molten steel and at least one perturbation at the surface sufficient to interrupt laminar flow of the molten steel in a boundary layer at the surface.

The article comprises a stopper rod, inner nozzle, metering nozzle, slide gate plate, pour tube, such as a submerged-entry shroud or submerged-entry nozzle, and combinations thereof. Interruption of laminar flow in the boundary layer is described as reducing diffusion of corrosive and erosive agents towards the surface.

One aspect of the invention shows a refractory piece having a perturbation at or near an inlet to or outlet of a bore of a refractory article. The perturbation is described as reducing precipitation at the inlet and outlet and promoting smoother

flow of the stream of molten metal through the bore. Such a perturbation can improve refractory life and casting efficiency. Another aspect of the invention includes a plurality of perturbations along the surfaces exposed to the stream of molten metal.

In another aspect of the invention, the perturbation is described as a discontinuity and comprises a protrusion or indentation in the surface that is taller or deeper, respectively, than the boundary layer is thick. For example, the discontinuity may be a step or groove. Alternatively or in combination with a step or groove, the discontinuity may comprise the intersection of two surfaces at a non-zero angle. The angle can vary depending on its location along the flow path. For example, an angle along the bore of a nozzle will typically be from four to twenty degrees, while at the entrance to a nozzle, the angle can be greater than sixty degrees. Similarly, a stopper rod can have an angle of ninety degrees.

In one embodiment, the perturbation is described as affecting the boundary layer over a working region. The working region has a length that is between four and twenty times the size of the perturbation. Depending on the length of the region, one or more perturbations may be necessary. The working region preferably includes those areas known to accumulate deposits that could interfere with casting.

In still another embodiment, the article is adapted to receive an inert gas that protects the molten steel from oxygen infiltration. The perturbation affects the boundary layer of steel in such a way that inert gas leaking into the molten steel and flows along the surface adjacent to the molten steel instead diffusing into the steel.

The method of the present invention includes disrupting laminar flow in a boundary layer adjacent to the surface without significantly affecting flow in a remainder of the stream. Non-laminar flow in the boundary layer is believed to

reduce diffusion of precipitating compounds to the surface and to improve the effect of inert gas injection.

Brief Description of the Drawings

Figure 1 shows a longitudinal cross-section of a refractory article of the present invention, specifically a collector nozzle.

Figure 2 shows a longitudinal cross-section of a variation of the collector nozzle.

Figure 3A shows flow contours of a boundary layer near a surface absent a perturbation.

Figure 3B shows flow contours of a boundary layer near a surface with a perturbation.

Figure 4 shows a longitudinal cross-section of a stopper rod in proximity to a collector nozzle.

Figure 5 shows a longitudinal cross-section of an outlet of a collector nozzle having a diverging section.

Detailed Description of the Preferred Embodiments

The present invention comprises a refractory article for use in casting a stream of molten steel through a bore from a first metallurgical vessel to a second metallurgical vessel or mold. The article includes a surface adjacent to the stream and at least one perturbation on the surface. The perturbation is located sufficiently near the inlet or outlet of the bore to affect precipitation on the surface at these locations. The article may include a stopper rod, inner nozzle, metering nozzle, slide gate plate, pour tube, such as a submerged-entry shroud or submerged-entry nozzle, and

combinations thereof, which have at least one surface contacting the stream of molten steel.

A stream of molten steel can be described as a combination of flow regions having laminar, turbulent and transitional flow regimes. Flow regimes are often identified based on their Reynold's numbers, which is a dimensionless number that relates inertial and viscous effects in a fluid. Reynold's number, Re, equals:

$$\varrho * V * D / \eta,$$

where ϱ is the density of the fluid, V is the velocity, D is the diameter of the bore, and η is the viscosity of the fluid. When Re is less than about 2100, flow is laminar. A Re above about 3000 identifies turbulent flow. Vaules of Re between 2100 and 3000 correspond to transitional flow, where the stream exhibits both laminar and turbulent flow patterns.

Laminar flow means a state of fluid flow where the flow moves along parallel, ordered paths. Laminar flow results in lower friction on adjacent surfaces, but has problems following retreating or protruding surfaces. Fluid flow that is immediately adjacent to a surface forms a boundary layer that is commonly laminar. The size of the boundary layer depends on physical properties of bore and the Reynold's number. In contrast to laminar flow, turbulent flow is a state where the particles move in irregular, wavy paths. Turbulent flow causes more friction on adjacent surfaces, but can more easily follow retreating or protruding surfaces.

Precipitation can occur, if at all, on surfaces adjacent to the stream of molten metal. Along these surfaces, boundary layers exist that usually present with laminar flow. Laminar flow is believed to promote precipitation. In the present invention, a

perturbation disrupts laminar flow in the boundary layer, thereby reducing precipitation on adjacent surfaces. Additionally, turbulent or transitional flow tends to decrease pressure in the fluid. This feature is relevant to gas-injection as will be explained in greater detail later.

A perturbation comprises an alteration in a surface adjacent to the stream of molten metal. The perturbation can be any alteration in the surface and should be sufficiently large to disturb laminar flow of the boundary layer but not so large as to affect significantly the flow regimes of the bulk fluid, such as the creation of "dead" zones. A "dead" zone is a region downstream of a discontinuity in which the pressure is substantially reduced relative to the bulk of the stream and small vortexes appear. Alterations in the surface include any discontinuity that affects the boundary layer, and can include indentations, grooves, protrusions, such as bumps or ridges, or the intersection formed by two surfaces. The latter includes, for example, the transition from a straight bore to a diverging bore. During casting, a boundary layer of steel commonly extends about 1-2 mm perpendicularly from the surface. A perturbation slightly larger than the boundary layer, that is, from 3-10 mm, can disrupt laminar flow in the boundary layer. Such a perturbation is typically smaller than "steps" found in prior art.

Figure 1 shows a nozzle 1 of the present invention. The nozzle 1 has an inner surface 2 defining a bore 3 with an inlet 4 and an outlet 5. In the embodiment shown, the inlet 4 includes a first perturbation 6 in the form of a step and a second perturbation 7 comprising an intersection of two surfaces. The perturbations 6 are exaggerated for clarity. An alternative embodiment in Figure 2 shows the first perturbation 6 as a groove near the inlet 4 of the nozzle 1.

A perturbation affects a boundary layer of a stream of molten steel near a surface 2. Absent a perturbation, the boundary layer would normally exhibit laminar flow as shown in Figure 3A, in which flow contours 8 appear parallel to the surface 1. A perturbation 6, as shown in Figure 3B, interrupts the boundary layer and changes the flow from laminar to transitional or turbulent. Flow contours 8 near the surface are no longer parallel and can develop eddies or vortexes that promote mixing of the fluid. Such non-laminar flow can reduce precipitation and decrease fluid pressure near the perturbation 6.

A perturbation typically affects flow patterns over a working surface that is as long along the bore as four to twenty times the size of the perturbation. In other words, a perturbation of 3 mm can affect the boundary layer for 12-60 mm along the length of the bore. The geometry of the refractory article, the type of steel being cast, and casting conditions will determine the placement, size and number of perturbations in a refractory article. One skilled in the art would identify such parameters after identifying the likely locations where precipitation can occur. Frequently, more than one perturbation may be necessary. Conveniently, these perturbations may be arranged in series along at least a portion of the bore, where precipitates are more likely to form.

Advantageously, a perturbation can be placed at an inlet or outlet of a bore. Figure 4 shows a stopper rod 9 in combination with a nozzle 1. The angle 15 of the stopper nose can be from about twenty to seventy degrees, and is typically about forty to sixty degrees. Precipitation on the nose 10 of the stopper rod 9 can seriously affect the metering of the stream of molten metal. When the nose 10 of the stopper rod 9 is

near the entrance 4 of the nozzle 1, a perturbation 6 on the surface of the nose 10 can alter the boundary layer to resist precipitation.

Similarly, an outlet of a collector nozzle includes a bore 3 having a perturbation 6 near the outlet 5 of the nozzle 1. The perturbation 6 includes a discontinuity 11 formed by the intersection of two portions of the inner surface 2 that define the bore 3. The size of the perturbation 6 is measured as the orthogonal depth 12 of the perturbation relative to the bore 3. At the outlet 5, a collector nozzle may also include a diverging section 13 having a diverging angle 14 defined by the inner surface of the diverging section and the direction of the stream. The diverging angle is between about four to twenty degrees. Diverging sections have been described as reducing the formation of metal droplets by reducing the pressure drop, and resultant shear stresses, from within the bore to outside the bore. Conveniently, the diverging section 13 will be about four times the size of the perturbation.

A perturbation affects laminar flow in a boundary layer and changes the velocity of the stream of molten metal at the boundary layer. Velocity and pressure are inversely related as explained by Bernoulli's law. As velocity increases around a perturbation, pressure decreases. Such a decrease can be exploited for the injection of an inert gas, such as, for example, argon. Inert gas is frequently used to protect the stream of molten steel from contact with oxygen and the resultant oxidation and precipitation.

Ideally, inert gas diffuses into the bore and covers the inner surface, thereby enshrouding the stream. In prior art, the inert gas is frequently injected at higher than desired pressure to overcome the resistance from pressure in the boundary layer. High-pressure, injected gas can escape from the surface and dissolve in the molten

steel stream. This limits the amount of inert gas actually enshrouding the stream and causes defects in the final product because of dissolved gas bubbles.

A perturbation induces non-laminar flow in the boundary layer and, therefore, lowers pressure in the boundary layer and also at the inner surface. The pressure needed to inject inert gas decreases. The injected gas can be at a low enough pressure that it remains on the surface and, because of the relatively higher pressure away from the boundary layer, the inert gas does not easily diffuse away from surface into the molten steel. The inert gas remains along the inner surface where the gas more effectively can enshroud the steel from oxygen.

Obviously, numerous modifications and variations of the present invention are possible. It is, therefore, to be understood that within the scope of the following claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. A refractory article for use in controlling a stream of molten metal during continuous casting comprising a working surface adjacent to the stream, characterized by at least one perturbation in the working surface sufficient to create non-laminar flow in a boundary layer of the stream and without significantly affecting flow in a remainder of the stream.

2. The refractory article of claim 1, characterized by the article comprising a stopper rod, nozzle, shroud, slide gate plate or combinations thereof.

3. The refractory article of claim 1, characterized by the article comprising an inner surface defining a bore, the bore having an inlet and an outlet, and at least a portion of the bore comprising the working surface.

4. The refractory article of claim 3, characterized by the perturbation being near the inlet.

5. The refractory article of claim 1, characterized by the working surface comprising a nose of a stopper rod.

6. The refractory article of any one of claims 1-5, characterized by the perturbation comprising a discontinuity.

7. The refractory article of any one of claims 1-5, characterized by the discontinuity comprising a step.

8. The refractory article of any one of claims 1-5, characterized by the discontinuity comprising a groove.

9. The refractory article of any one of claims 1-8, characterized by the discontinuity being immediately upstream of a diverging section.

10. The refractory article of any one of claim 1-9, characterized by the article including a gas-injection apparatus.

11. The refractory article of claim 10, characterized by the gas-injection apparatus comprising a porous refractory.

12. The refractory article of claims 10 or 11, characterized by the gas-injection apparatus being adapted to inject gas at the perturbation.

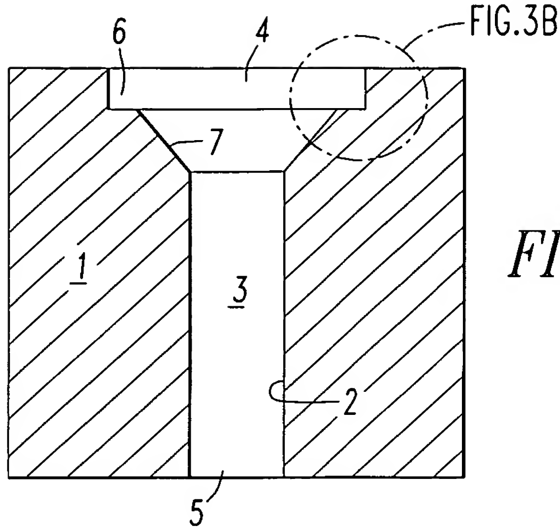


FIG.1

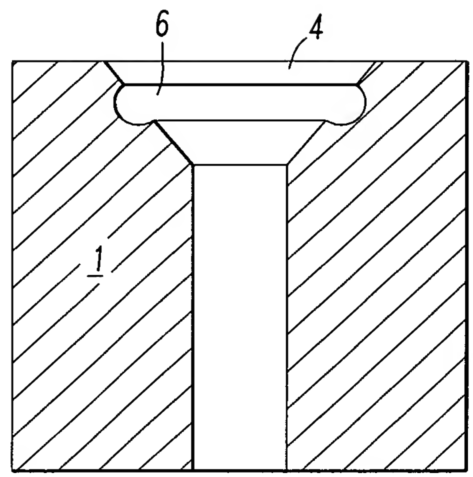


FIG.2

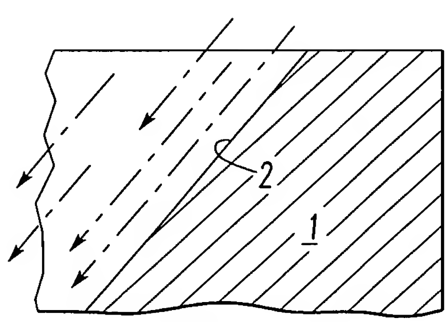


FIG.3A
PRIOR ART

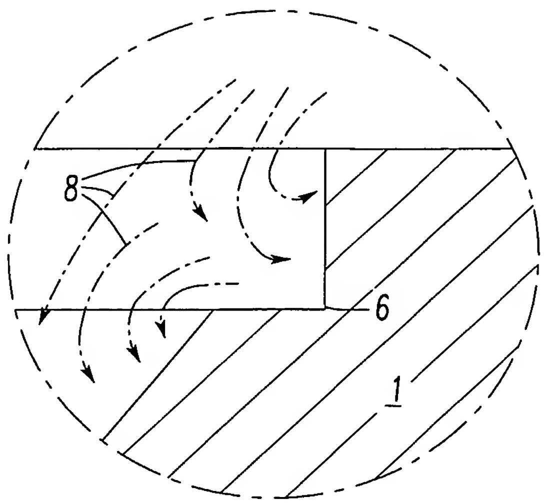


FIG.3B

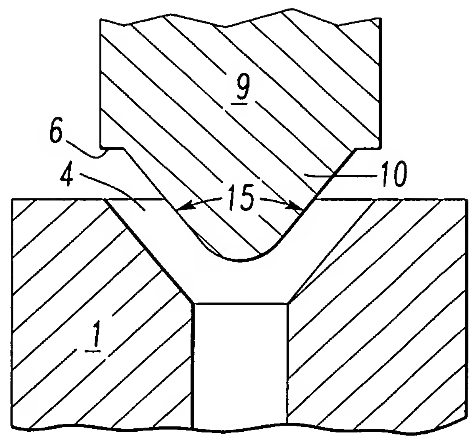
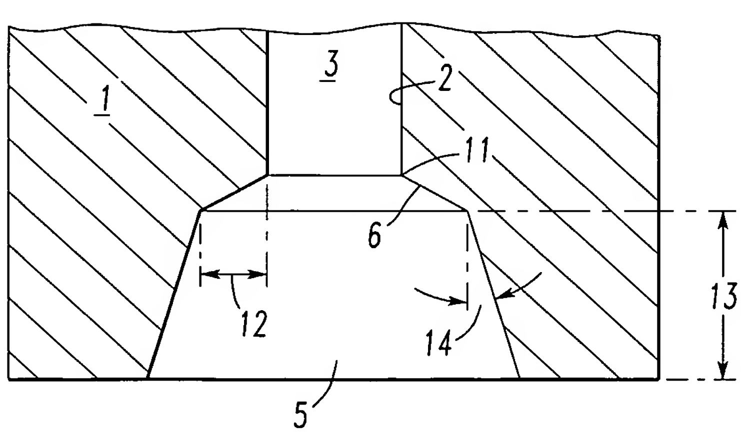


FIG.4

FIG.5



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